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Evaluation of water resources carrying capacity in Anhui Province based on association analysis model in the context of digital transformation

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ABSTRACT

The breadth and range of water activities in China have expanded along with the social economy's and population's ongoing expansion. In this environment, people are attach importance to water resources. The target area for this study is Anhui Province. To conduct a detailed analysis of the water resource carrying capacity of the region and use its evaluation results to promote the development of the regional economy, this research first explained the relevant connotation of water resources. After that, a methodology for assessing the carrying capacity of water resources that uses Logistic Grey Correlation Analysis was constructed. This study will use the constructed model to assess the water resource carrying capacity of various regions in Anhui Province in the recent past. The carrying capacity of water resources was dynamically evaluated, and the findings indicate the correlation analysis model can clearly display the situation of water resource carrying capacity in various regions of Anhui Province. Furthermore, by utilizing digital transformation technology, the government can achieve a better performance in predicting and allocating carrying capacity of water.

Keywords: Correlation analysis; Anhui Province; Water resource carrying capacity; Dynamic evaluation

1. Introduction

Water is a natural resource that restricts the natural environment and human survival, supporting the creation of an ecological environment and the growth of human civilization and economy. The shortage of water will have a remarkable negative impact on food safety and supply, so water is also a strategic economic resource for human survival. Water problems, such as water shortage, uneven distribution, not only threaten the food security and energy security of human society, but also constrain the global economy and sustainable development [1]. Water resource system is the foundation of sustainable economic and social development, which provides water for regional economic development and people's basic production and life. Therefore, it is critical for economic society and water resources to grow together [2]. However, with the continuous advancement of economy and society, China is increasingly using water resources. However, as for water resource protection and water pollution prevention, China has failed to take appropriate governance measures, and there are still certain drawbacks at present. The carrying capacity of water resources is a comprehensive global indicator that significantly affects the natural environment and local economy [3]. Its ability to conduct macro evaluation and micro diagnosis of regional water resource carrying capacity is a key link in achieving water resource regulation and rational allocation. In addition, the important link in building a regional water resources monitoring and early warning mechanism cannot be separated from the assessment of water resources carrying capacity (WRCC) [4]. Scientific assessment of the carrying capacity of regional water

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resources is a key role in implementing the "Three Red Lines" and achieving sustainable development of regional economy and society [5]. In view of this, this study will use correlation analysis to study various indicators of water resources in various regions of Anhui Province in recent years. The research aims to give a precise and dynamic assessment of Anhui Province's WRCC.

2. Related work

For urban agglomerations to expand sustainably, enough water resource carrying capacity is crucial. Currently, many scholars have established different analytical models for water resource carrying capacity to solve more scientific and stable water resource development strategies. Zhang et al. [6] carried out research on water resources in Dongting Lake basin, and constructed the model by combining the analytical hierarchy process with the entropy weight approach. To examine the temporal development and geographical distribution properties of the WRCC of the basin, the experiment computed the WRCC of the Dongting Lake basin from 2009 to 2018. In response to the severe water resource shortage and ecological vulnerability problems faced by Xinjiang for a long time, scholars such as Świąder et al. [7] selected evaluation indicators such as water resources, society, economy, and ecology, and constructed a comprehensive evaluation index. Experiments analyzed the water resource carrying status and spatiotemporal evolution characteristics in some regions of Xinjiang, and the results showed that the proposed model has good applicability. To accurately predict the carrying capacity of regional water supplies, Zhao et al. [8] established a quantitative dynamic prediction model for WRCC based on the mutual feedback mechanism of the "economic society water supplies ecological environment" system. The experiment used this model to diagnose WRCC in the Yellow River, and the results verified that the constructed model could provide the optimal regulation scheme for the Yellow River. Based on the supply and demand relationships of different water sources and types, researchers such as Guiamel and Lee [9] constructed a model that combines quota calculation and linear weighted goal programming. The model was used to the evaluation of WRCC in Baoding Plain. The simulation results showed that the model can achieve the classification of water resource carrying capacity in the selected area, and had good applicability. Reddy and Kumar [10] assessed the urban WRCC using a multi criteria compromise ranking method. The experiment first constructed comprehensive evaluation indicators for WRCC, and assigned weights to these indicators. After that, the model was applied to the comprehensive assessment of WRCC in Weifang City. The results showed that the level of water resources development and utilization in this region exceeds the local WRCC, verifying the better practical significance of the proposed model.

Association analysis model is an effective scientific analysis method, which is favored by scholars from all walks of life. It has also shown good practicality in related fields. Eer et al. [11] used association analysis models and statistical tools to study the genetic control mechanism of brown sheep growth and development. The experiment focused on exploring the correlation between growth and reproductive genes between brown sheep and Hu sheep, and the experimental results showed that there were genetic differences between different sheep groups. Therefore, this study also demonstrated the applicability of the association analysis model. Jiang et al. [12] combined a generalized linear mixed model and a correlation analysis model to discuss the data from the British Biobank. It was verified that the studied data could achieve good control over the characteristics of the contrast ratio under zero and extreme conditions, and could achieve good calibration. Meanwhile, the model proposed in this study had better statistical characteristics and higher computational speed. To investigate the relevant influencing factors of organizational culture, scholars such as Bhuiyan et al. [13] proposed a structural equation model experiment combined with correlation analysis to study corporate culture's direct effects on both financial and non-financial performance. The findings revealed that whereas innovation culture was adversely connected with both financial and non-financial performance, a team-oriented culture was favorably correlated with both. This study was helpful in studying the subsequent impact of organizational performance in emerging economies. To analyze the impact of corporate social responsibility companies on enterprises, researchers such as Kamran et al. [14] used correlation analysis models and fuzzy TOPSIS theory, and weighted various influencing factors. The results of correlation analysis indicated that corporate social responsibility was crucial. This research could provide important value information for relevant decision makers, and had great help for decision makers' decision-making work. To effectively forecast the pertinent e-commerce market dynamics and increase the overall value of the circular e-commerce industry, Peng et al. [15] used the Grey System Theory and correlation analysis model to analyze it. It was verified that the model was crucial in the analysis of data from the e-commerce market's circular economy. It also validated the far-reaching practical significance of the association analysis model.

To sum up, there have been many scholars discussing water resource carrying capacity, and some achievements have been achieved. However, there are still some unresolved issues. Meanwhile, the relevance analysis model has a good applicability for this topic. Therefore, this study selected a correlation analysis model to study various indicators of water supplies in various regions of Anhui Province in recent years, with the aim of providing innovative methods for dynamic assessment of WRCC in the province.

3. Application of Logistic Grey Correlation Analysis in the evaluation of WRCC

3.1. Connotation analysis of water resource carrying capacity

WRCC refers to the maximum population, economic, and social utility that a local water resource system can carry within a defined time and space range and meet the conditions that can be predicted by the level of scientific, technological, economic, and social development [16].

WRCC is also the overall reflection of the mutual support and interaction between modern society and economy. The magnitude of WRCC can also have an important impact on local sustainable development from a lateral perspective. WRCC not only has different forms of expression, but also has diverse connotations. This connotation includes sustainable connotation, space-time connotation, and socio-economic connotation.

Among the three connotations mentioned above, sustainable connotation refers to a relevant guiding ideology based on the study of regional WRCC. There is a prerequisite for WRCC. Effectively maintaining the good development of the local ecological environment can provide a backup force for the common development of population, economy, and society in a sustainable manner [17,18]. There are two ways to describe the regional water resources' sustainability. First, water resource development and use must follow sustainable development principles. That is, the ecological environment should be taken protecting to promote the population development, and maintain the harmony and stability of supplies and the environment as the benchmark. Secondly, in the process of continuous socio-economic development, the improvement of any appropriate technology related to the development and utilization of water resources will enhance the WRCC of the region.

The spatiotemporal connotation is a significant connotation that all regional WRCC has, which is divided into two parts: temporal connotation and spatial connotation, collectively referred to as spatiotemporal connotation [19]. The connotation of time is usually manifested in two aspects. Firstly, WRCC represents the carrying capacity of corresponding water resources in various time scales in the future. In short, the load situation of water resources in the future has a specific and unique time connotation. Secondly, the structure and composition of water resources will change as different influencing factors change. The level of socio-economic development, changes in the ecological environment system, and the level of technology used to develop and utilize water resources are all important components of the influencing factors [20]. On the other hand, there are also two forms of expression of spatial connotation. One is that the carrying capacity of the local water supplies must correspond to a certain range of research areas. If there is no phenomenon of water diversion from outside the basin, the regional water resources only correspond to the water resources of the region. Secondly, because the same water resources are located in different regions, they will be affected by different terrain, geomorphology, meteorological conditions, and other factors in each region, so there will be differences in WRCC [21].

The manifestation of socio-economic connotation in regional WRCC is mostly split into three sections. First, there is a close correlation between the WRCC and its development goals, and to a certain extent, it is affected by people's consumption levels and habits. Therefore, different socio-economic development goals will have different water resource carrying capacities. Secondly, the fundamental basis for the WRCC of the region is the expected level of socio-economic and technological development. This includes the investment and construction level, development and utilization level, and corresponding management level of water resources. Thirdly, through reasonable optimal allocation of regional water supplies, corresponding WRCC can be obtained [22].

3.2. Construction of water resource carrying capacity evaluation model based on Logistic Grey Correlation Analysis

Logistic function is a simple and widely used correlation analysis algorithm that can fit the curves formed by sample series and standard series, thereby determining the degree of correlation between sample series and evaluation criteria [23]. The logistic function presents an "S" shaped curve, and the function model for fitting processing is shown in Fig. 1. This study chose to use this function to fit the curve formed by the corresponding sequence, including sample sequence and standard sequence [24]. After fitting, the corresponding correlation degree between the evaluation criteria and the evaluation criteria can be obtained. The similarity between curves is represented by ξ, and $\xi \in [0,1]$. The higher the value of ξ, the better the correlation degree of the curve fitting, which indicates the higher the correlation degree between the two sequences [25].

In Fig. 1, the abscissa is the absolute difference between all corresponding elements in the sample sequence and the standard sequence; The ordinate is the corresponding correlation coefficient. The diagram is split into three levels, namely, the loadable stage, the critical stage, and the overload stage. All stages correspond to levels 1–3. In addition, in Fig. 1, A and B respectively represent the function points when the second-order inverse value of the function is 0. The expression for this function is shown.

$$\xi = 1 - \left(\frac{k}{1 + e^{-a(x-c)}} \right) \tag{1}$$

where a represents the growth rate; k represents the saturation coefficient of the function; And c is a constant. According to the above functions, a dynamic assessment model for regional WRCC based on the Logistic Gray Correlation Model can be constructed according to the steps. Firstly, it is necessary to construct an evaluation sample sequence and a hierarchical standard sequence. Record the sequence matrix of the former as $X = \{x_{ij} | i = 1\ m; j = 1\ n\}$

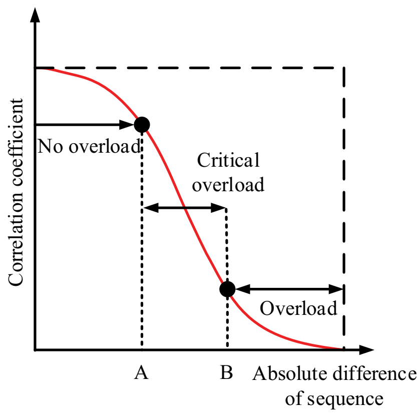

Fig. 1. Grey correlation model of logistic function.

. Wherein i denotes the sequence number of the former; j denotes the sequence number of the latter; m is the total value of the evaluation sample; n is the total number of indicators. Therefore, x_{ij} denotes the value of the j-th evaluation index of the i-th sample. In addition, it is also necessary to establish an evaluation grade standard system. In the specific construction process, the optimal values of all indicators in the sample set are taken as the core to divide the water resource carrying capacity into different levels, with a total number of levels being s. Record the evaluation grade standard system as $Y=\{y_{kj}|k=1\,s;j=1\,n\}$; m, n, and j have the same meanings as above; k indicates the evaluation level of the k-th level. Based on this, y_{kj} represents the indicator value corresponding to the j-th evaluation indicator in the k-th evaluation level. Subsequently, a dimensionless normalization process is required. Different types of indicators require different equations. The calculation equations for forward and reverse indicators are shown in Eqs. (2) and (3), respectively.

$$x'_{ij}=\frac{x_{ij}-\min\limits_{1\le i\le m}x_{ij}}{\max\limits_{1\le i\le m}x_{ij}-\min\limits_{1\le i\le m}x_{ij}}\left(1\le i\le m,1\le j\le n\right) \quad (2)$$

$$x'_{ij}=\frac{\min\limits_{1\le i\le m}x_{ij}-x_{ij}}{\max\limits_{1\le i\le m}x_{ij}-\min\limits_{1\le i\le m}x_{ij}}\left(1\le i\le m,1\le j\le n\right) \quad (3)$$

where x'_{ij} is the result of the corresponding j-th assessment index in the i-th evaluation sample, that is, the normalized value. The sample set subjected to the normalization process described above can be rewritten as $X'=\{x'_{ij}|i=1\,m;j=1\,n\}$. Next, it is necessary to calculate the grey correlation coefficient of the Logistic function and the number of connections between the Logistic grey correlation degree and the assessment of WRCC. The last step is to calculate the corresponding characteristic values of the supporting capacity, pressure, and regulatory capacity of water resources through relevant means of attribute recognition. The equation is shown below:

$$h_i=\min\left\{k^*\left|\sum_{k=1}^{k^*}\mu_{i,k}>\lambda\right.\right\} \quad (4)$$

where λ represents the confidence level, and $\lambda\in[0.50,0.70]$. The magnitude of the value of λ is positively correlated with the reliability of the evaluation results. Based on this, a corresponding risk matrix can be constructed, and the supporting capacity, pressure, and water resources' regulatory capacity can be calculated using Eq. (4). After that, the subsystem evaluation level is established, and one-dimensional real numerical variables are finally synthesized to replace the two-dimensional real numerical variables before calculation. The synthesis method is shown in Table 1.

According to Table 1, when synthesizing the risk matrix, there are certain variations in the role relationships in water resource carrying capacity. The support force is the largest, the pressure is the second, and the regulating force is the smallest. When synthesizing subsystems of support and regulatory forces, support forces occupy an important and dominant position. Regardless of whether the support force level is 1, 2, or 3, the control force level is all level 1, and the results are mainly based on the support force. When synthesizing subsystems of stress and regulatory forces, the synthesis rules are similar to those described above.

4. Empirical analysis of WRCC evaluation model based on Logistic Grey Correlation Analysis

At the confluence of the Yangtze and Huai Rivers lies Anhui Province. Due to the combined effects of monsoon and terrain, its climatic conditions are complex and precipitation is unevenly distributed across space. Therefore, drought and flood frequently occur in the province, water resources development and utilization are difficult, and the level of effective water use and water conservation is low. This study uses the WRCC evaluation model based on Logistic Grey Correlation Analysis to calculate the WRCC of different regions in Anhui Province in the past 5 y. According to the calculated degree of identity, difference, and opposition in various regions of Anhui Province. Then, it is combined in pairs to obtain the corresponding absolute difference, gray correlation degree, and connection number calculation value. Finally, the evaluation levels of various aspects of WRCC are obtained through attribute recognition. The change trend of the WRCC subsystem is shown in Fig. 2.

Divide the relevant connection number interval represented by the ordinate in Fig. 2, and divide the initial interval [–1, 1] into five sub intervals, are [–1, –0.6), [–0.6, –0.2), [–0.2, 0.2), [0.2, 0.6], and [0.6, 1]. Through the above division operation, the correlation coefficient can be carefully allocated, which is conducive to a thorough analysis of the variations in WRCC among regions in Anhui Province. According to Fig. 2, it can be seen that the supporting capacity subsystem

Table 1
Relevant risk matrix of synthetic water resource carrying capacity subsystem

Regulatory force subsystem level	Support subsystem level		
	1	2	3
1	1	2	2
2	1	2	3
3	1	2	3
Regulatory force subsystem level	Pressure subsystem level		
	1	2	3
1	1	2	2
2	1	2	2
3	1	2	3
Pressure regulatory force subsystem level	Supporting force – regulating force subsystem level		
	1	2	3
1	1	2	2
2	1	2	3
3	2	2	3

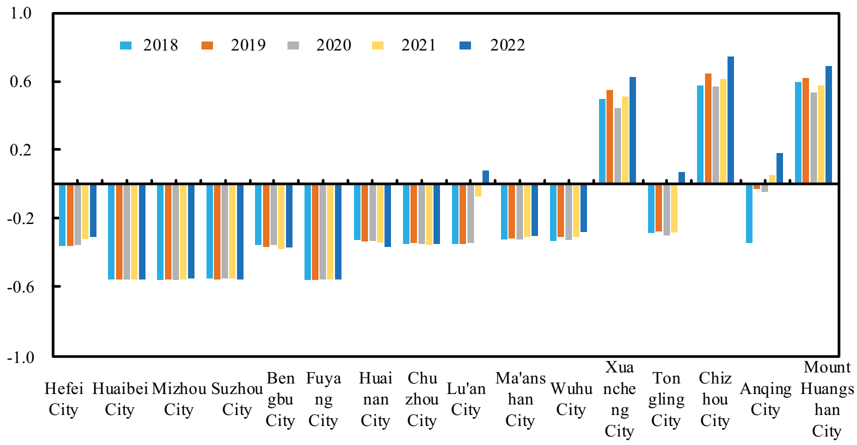

Fig. 2. Change trend of supporting capacity subsystem of water resource carrying capacity.

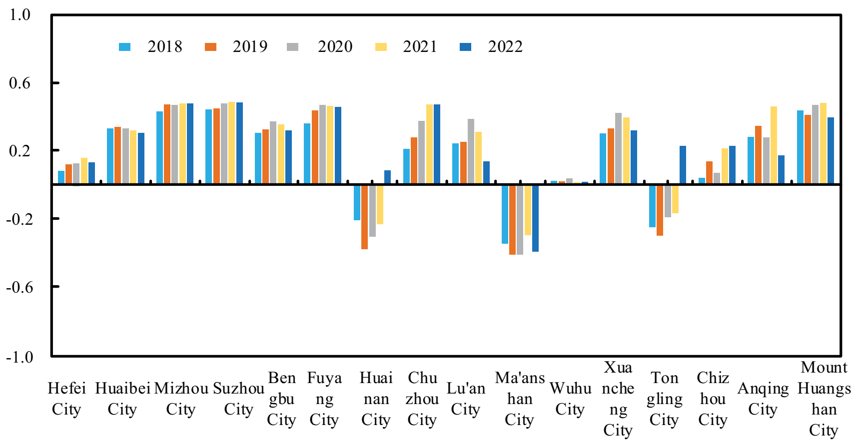

Fig. 3. Change trend of pressure subsystem of water resource carrying capacity.

in the WRCC of each region in Anhui Province has a trend of improving year by year. Among them, the southern Anhui region is significantly superior to other regions. The change trend of the WRCC pressure subsystem is shown in Fig. 3.

There are some similarities between Figs. 2 and 3. Both of them are data analysis of Anhui Province in the five years 2018–2022, and the connection number interval is also divided. According to the detailed observation results of Fig. 3, the WRCC pressure subsystem in northern Anhui is the best, with its carrying pressure significantly lower than that in central and southern Anhui. As industrialized cities, Tongling City, Ma'anshan City, and Huainan City have greater bearing pressure than other cities, and have certain significance. In the other part, the change trend of the WRCC regulation capacity subsystem is shown below.

Fig. 4 shows the change trend of the regulatory power subsystem in various urban areas of Anhui Province within 5 y. According to the figure, in 2021, Bengbu, Xuancheng, Mount Huangshan, Chizhou, Ma'anshan, Tongling and Chuzhou will have more connections than other years. On the whole, the regulatory capacity of WRCC in various regions in Anhui Province has become better year by year, and the development trend is good. To gain a deeper and comprehensive understanding of the overall situation of WRCC in Anhui Province in recent years, this study also analyzed the impact of WRCC on the province's economy and population from 2010 to 2022. The results are shown in Fig. 5.

In terms of the overall situation of the province, the WRCC of Anhui Province fluctuated greatly from 2010 to 2022. The reason for this phenomenon is that total water resources varies every year. When water resources are abundant in a given year, the population and economy that can be carried are both large and significantly superior to those in years of water scarcity. Specifically, the years 2015, 2017, and 2019 in Fig. 5 are years of water scarcity, with significantly lower WRCC. From 2019 to 2022, the WRCC of Anhui Province increased yearly. In addition to the overall situation of WRCC, this research also in-depth analyzed the impact of WRCC on population and economy in Anhui Province from 2010 to 2022. Fig. 6 for the water resources bearable population in each region.

From Fig. 6, it can be seen that 2019 is a node with significant changes in WRCC. Before this time node, the WRCC of northern Anhui was remarkably higher than that of

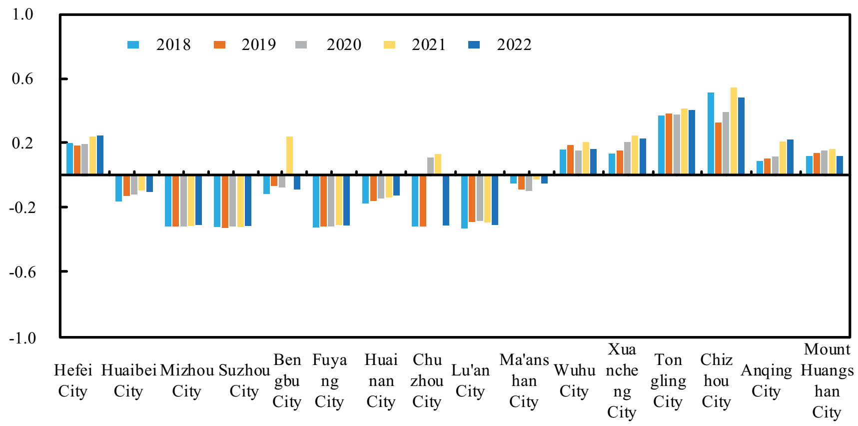

Fig. 4. Change trend of regulatory capacity subsystem of water resource carrying capacity.

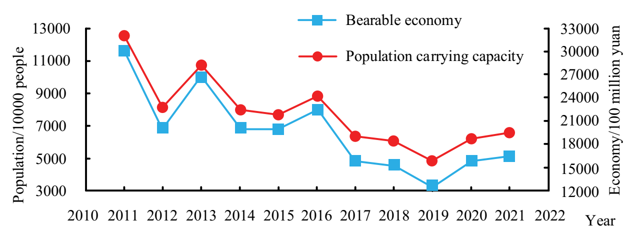

Fig. 5. Overall situation of WRCC in Anhui Province from 2010 to 2022.

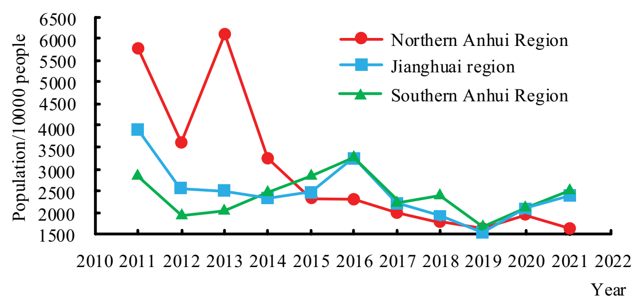

Fig. 6. Population that can be carried by water resources in various regions of Anhui Province.

Jianghuai and southern Anhui. The specific performance is that the water resources in northern Anhui can be carried by the population of about the sum of the Jianghuai region and southern Anhui. Even in 2017, the population that can be carried in northern Anhui reached 60 million person-times, far higher than the 25 million person-times in the Jianghuai region and the 20 million person-times in southern Anhui combined. After this time node, the number of people whose water resources can be carried in the above three regions gradually approaches. Meanwhile, the economic situation in various regions where water resources can be carried is also changing, as detailed analysis is shown below.

Fig. 7 shows that water supplies in various regions of Anhui Province can carry the economy, almost in line with the changing trend of the population that can be carried. The northern Anhui region is significantly superior to the Jianghuai and southern Anhui regions in terms of

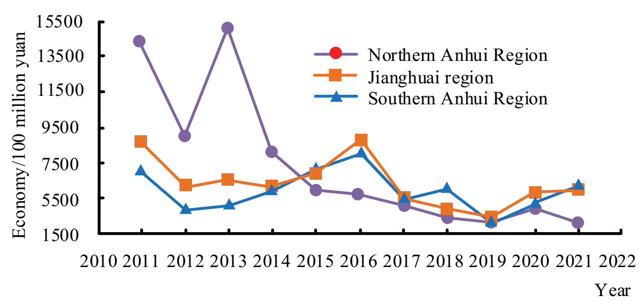

Fig. 7. Economies that can be carried by water resources in various regions of Anhui Province.

population and economy. This is because the comprehensive water consumption in northern Anhui is relatively small, and its regional economic and social development is not as good as the other two regions. This situation leads to a better population and economy that can be carried than the other two regions. It also indicates that the carrying capacity of the region's water resources and its degree of socio-economic development are linked in several ways.

Fig. 8 shows the spatial distribution results of the WRCC linkage coefficient in Anhui from 2018 to 2022. From the figure, the support capacity for water resources in the northern and central regions is relatively weak. In 2019, the support capacity for water resources in the central region is relatively weak, while in 2022, the support capacity for water resources in the whole province is relatively weak. The supporting capacity of southern Anhui for WRCC is stronger than that of northern Anhui and central Anhui. From 2018 to 2022, Xuancheng, Chizhou and Mount Huangshan have the best supporting capacity for WRCC in the province. Xuancheng City, Chizhou City and Mount Huangshan City have a great supporting force. From the analysis of the original data. The per capita water resources, water production modulus, per capita water supply and vegetation coverage of these three cities are all level 1. The model assessment's findings are in line with the reality.

In Anhui, from 2018 to 2022, Fig. 9 depicts the hierarchical geographical distribution of each city's water resource carrying capacity. From the figure, the evaluation results based on Logistic Grey Correlation Analysis and Risk

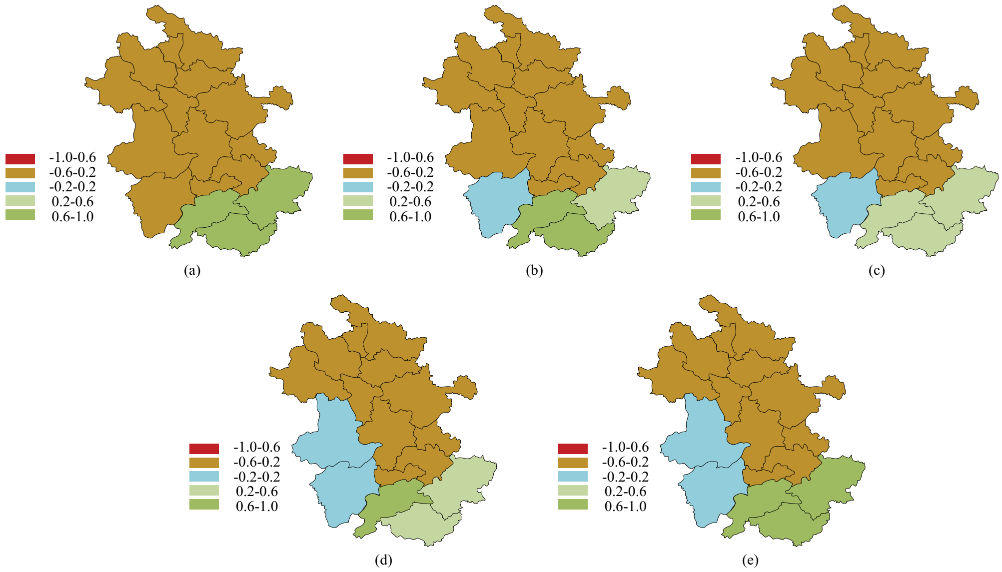

Fig. 8. Spatial distribution results of water resources bearing and supporting capacity coefficient in Anhui Province. (a) 2018, (b) 2019, (c) 2020, (d) 2021, and (e) 2022.

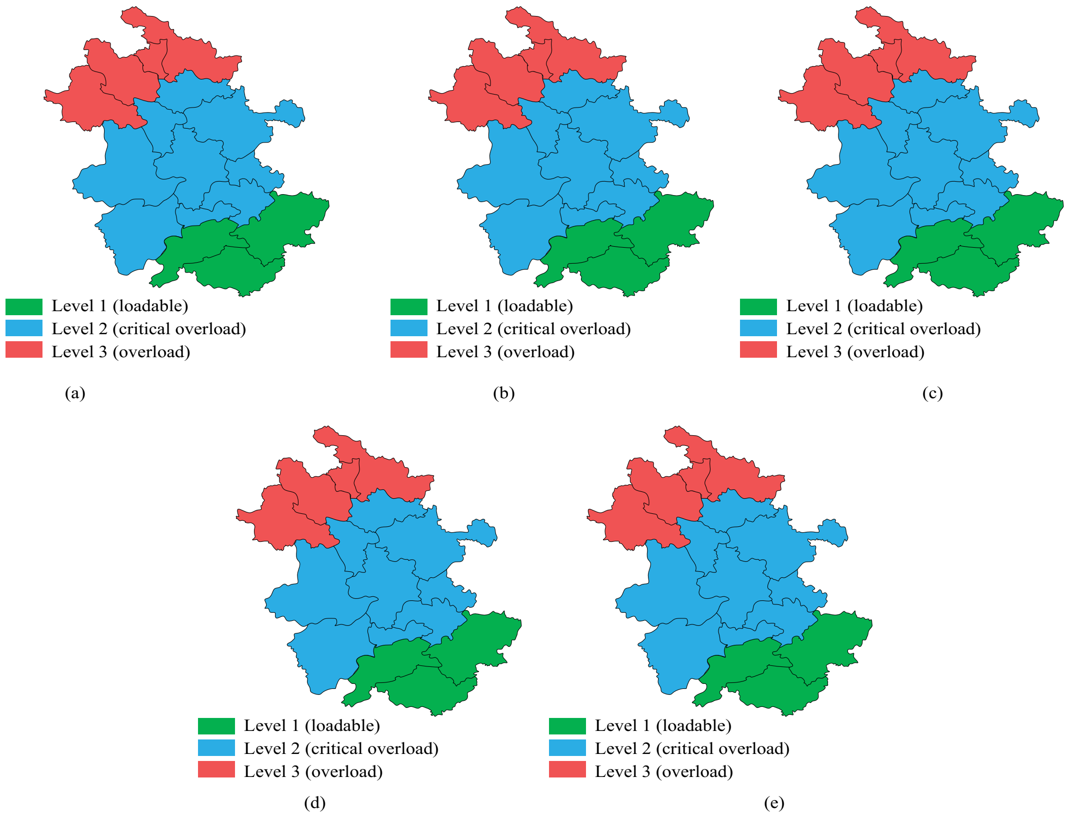

Fig. 9. Assessment results of spatial distribution of water resource carrying capacity in Anhui Province based on risk matrix. (a) 2018, (b) 2019, (c) 2020, (d) 2021, and (e) 2022.

Matrix Method are comprehensive and reasonable, and closer to the actual situation. The main reason is that the risk matrix can avoid one-sided adoption of the worst elements, making the final result more reasonable. From the perspective of the spatial pattern of WRCC in Anhui from 2018 to 2022, southern Anhui is superior to central Anhui, while northern Anhui is superior to northern Anhui, which is determined by the relative importance of WRCC. The problem of excessive WRCC in northern Anhui has long existed, which is closely related to the insufficient support capacity for water resources. In addition, the per capita water resources, water production modulus, per capita water supply, and vegetation coverage in northern Anhui are closely related to the region's location. The water resources and other natural conditions in northern Anhui do not have advantages. Therefore, relevant departments must take corresponding countermeasures to enhance the WRCC.

5. Conclusion

In the construction and development of human civilization, water supplies occupy an important and inaccessible position. Water resources are vital to the growth of business, agriculture, and the preservation of the natural environment. To solve the current water resource management problems and improve the utilization rate of water resources, this study takes the water resource carrying capacity of various regions in Anhui Province as the research object, and conducts in-depth analysis of it. The experiment constructed a correlation analysis model to explore the relevant connotation of water resources and the WRCC of various regions in Anhui Province in recent years. The simulation results show that the supporting capacity subsystem of WRCC in various regions of Anhui Province is significantly superior to other regions in southern Anhui; The WRCC pressure subsystem in northern Anhui is the best, and its carrying pressure is significantly lower than that in central and southern Anhui; When the water resources in a certain year are relatively rich, the population and economy that can be carried are both large and significantly superior to those in years with insufficient water supplies; The water supply carrying capacity of northern Anhui Province is higher than that of southern Anhui and Jianghuai regions, and the WRCC affects the development of regional economy to a certain extent.

Based on the industrial and consumer Internet, Anhui Province can accelerate the improvement of digital development, value development of water management capabilities. Through developing energy-efficient water resources development and management digital systems to the cloud control platform as the core, Anhui can strengthen multi-dimensional data exchange and application to build smart water, energy-saving and high-efficiency scenarios, and build digital cities.

This study conducted a detailed analysis of the WRCC subsystem and achieved certain results. However, the regional data cited in the research process in Anhui Province are not comprehensive enough, and it is hoped that they can be improved in future research.

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